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Perception Under Road Lighting Conditions with Complex Surroundings

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1. Introduction

To perceive necessary visual information for safe driving at night, drivers of cars drive with the headlights on. Due to technical limitations, however, the drivers cannot perceive all the necessary visual information they need.

One of the efficient ways to improve the perceptual situation at night is to install road lighting along the whole stretch of roads, continuously (1). The lighting to be installed must comply with perceptual requirements to make the drivers able to perceive necessary visual information in time, to handle any situation they might face.

To provid such conditions, the CIE Recommendations for Lighting of Roads for Motorized Traffic (2) as well as the CIE Recommendations for Motor and Pedestrian Traffic (3), for example, specify some quality parameters concerning visual perception as follows (other than parameters concerning visual comfort):

1) The average road surface luminance (Lr)
2) The overall uniformity (Uo) of the road surface luminance
3) Admissible threshold increment (TI) (glare restriction)

2. Problems associated with the quality criteria of road lighting

Various investigations have revealed that perception improves as the average road surface luminance (Lr) increases (4) (5) (6), as the overall uniformity (Uo) increases (6) (7), and/or as the threshold increment (TI) decreases (7) (8).

This means that, if an average road surface luminance (Lr) lower than that specified in the CIE Recommendations is combined with a higher uniformity (Uo) , or a higher average road surface luminance (Lr) is combined with a lower uniformity (Uo), then the road lighting possibly provide necessary visual conditions, for safe driving.

The present CIE Recommendations (2) (3), however, specify each quality criterion independently and separately. This means that sometimes one criterion has a "needless" high value, meaning that the present CIE Recommendations sometimes result in an excessive quality for road lighting as far as the perceptual conditions are concerned.

3. Perception and objects

On and around the road, there are objects of a variety of apparent sizes and reflection factors (precisely, the luminance factors). Some of the objects are easy to perceive and others are difficult, even under the same lighting conditions. For traffic safety, the road lighting has to allow the drivers to perceive as many objects relevant to driving as possible.

In examining perception of objects in road lighting, therefore, it is important to choose an appropriate size and a reflection for the object.

3.1 Size of the object

3.1.1 Critical object

As is well known, the larger the object the easier the perception. This means, in doing study on perception in road lighting, in view of traffic safety, employing an object which is too big is not appropriate.

On the other hand, perception becomes more difficult as the object becomes smaller. Possible risk to traffic, however, decreases. For this reason, it is not necessary in studying perception to use an object which is too small to cause danger.

This discussion leads to the conclusion that the most suitable object for studying road lighting is an object which is difficult to perceive, i.e., the smallest object which still is dangerous to traffic (9).

For this reason, a square object with a height of 20 cm was chosen. The dimension is just comparable to the distance between the road surface and the lowest part of the body construction of normal cars. Such an object is sometimes called a "critical object" (9).

3. 1. 2 Size of the Critical object and practical objects

Sometimes the size of the critical object mentioned above is criticized as being too small in comparison with most objects encountered in normal traffic and consequently the lighting requirements will be too high.

The lighting requirements on the basis of a critical object, however, cannot be said to be too high. This is because, in most of the cases at night, large objects are not always seen against uniform and large backgrounds.

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Only portions of the large objects standing against a well-lit background are perceptible. Most backgrounds against which other parts of the large object are seen are dark and difficult to illuminate artificially. These include dark sky, mountains, bushes and buildings far ahead. Under such conditions, only small portions of the large objects in the night are visible against a bright background artificially lit. This means that to see a large object, visual conditions under which the critical object is perceptible are still necessary.

In addition to this, to judge the distance and the size of a large object far ahead, in the perspective of the driver's field of view, it is important to perceive the lower parts of it, such as the lower parts of the rear end wheels, contacting the road surface.

For these reasons, to perceive a large object and to judge its distance, drivers still need visual conditions under which the (small) critical object is perceptible.

3.2 Reflection factors of the critical object

3.2.1 Silhouette Vision and Reversed Silhouette Vision

To perceive objects, a sufficient luminance difference between the object and the background (ΔL) is necessary. This means that to make the object perceptible, the luminance of the object must be sufficiently either lower or higher than that of the backgrounds.

As is well known, if the object is seen to be darker than the background, it is called Silhouette Vision. This does not imply, of course, that the objects are seen as black silhouettes. The term Silhouette Vision means that the luminance of the object is lower than that of the backgrounds.

On the other hand, if the object is seen as lighter than the background, it is called Reversed Silhouette Vision.

Since the headlights illuminates objects almost only in the horizontal directions, this system makes vertical parts of the objects brighter than the horizontal road surface far ahead against which the objects are seen, and provides the Reversed Silhouette Vision. For this reason, with the headlighting systems, objects with high reflection factors are easily visible but not those with low reflection factors.

Road lighting, on the contrary, illuminates the road surface almost only in the vertical direction. Under such lighting conditions, the horizontal road surface is brighter than the vertical parts of the objects, depending, of course, on the reflection factor of the objects. Because of this, with the road lighting systems which provides the Silhouette Vision, objects with low reflection factors are easily perceptible.

Applying the curve in Figure 1, Waldram [11], and Harris [12], and van Bommel [7] have examined the probability of the existence of different reflection factors in pedestrian's clothing in relation to road lighting. Waldram called the probability as the Revealing Power of the road lighting [11].

3.2.2 Revealing Power

Smith [10] studied the cumulative probability of the existence of the reflection factor of pedestrians'clothing in the night as in Figure 1.

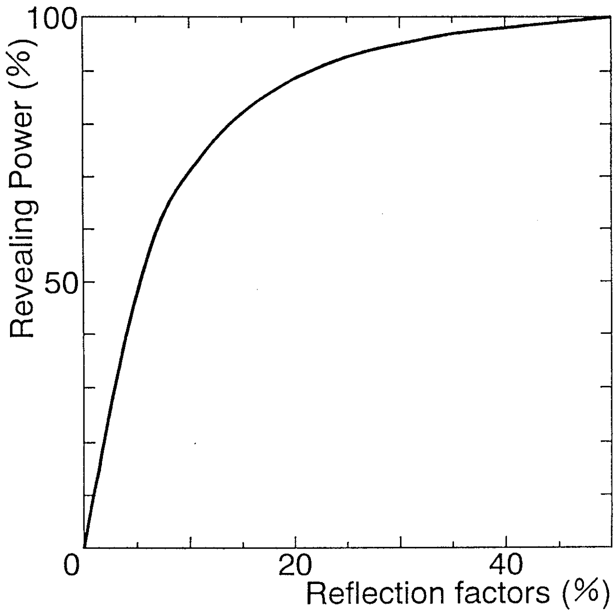

Fig. 1 Cumulative probability of the existence of the reflection factor of the pedestrians' clothing (Revealing Power for the Silhouette Vision)

Similar studies as to the cumulative probabilities of the existence of different reflection factors in pedestrian's clothing have later been conducted by others. Van Bommel [7], and Serizawa and others [13], for example, have found similar results.

3.2.3 Reflection factor of the critical object and the Revealing Power

Figure 1 shows the cumulative probability of the existence from the lower reflerction factors and shows the Revealing Power for the Silhouette Vision. Under certain road lighting conditions, if a critical object with a reflection factor of 20%, as an example, is just perceptible in the Silhouette Vision, then objects darker than the reflection factor of 20% are all perceptible unless they are too small. (Besides these, some objects are seen in the Reversed Silhouette Vision [12].)

From Figure 1, we see that the Revealing Power of the road lighting is about 90% or more (if the Revealing Power for the objects with higher reflection factors seen in the Reversed Silhouette Vision is taken into account).

Figure 2 shows the curve re-drawn, based on the Smith's study, to illustrate the cumulative probability of the existence of the reflection factor from higher reflection factors. This curve gives the Revealing Power for the Reversed Silhouette Vision.

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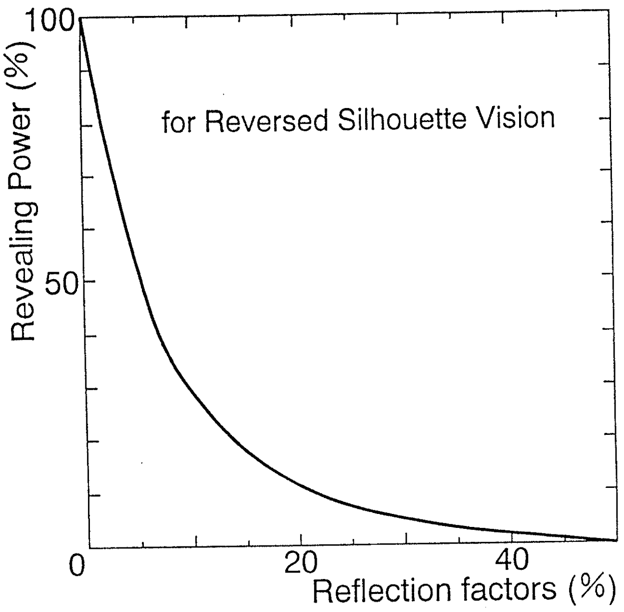

Fig.2 Cumulative probability of the existence of the reflection factor of the pedestrians'clothing (Revealing Power for the Reversed Silhouette Vision)

If with another lighting situation (for example headlighting) the critical object of 20% is just perceptible in the Reversed Silhouette Vision, then only objects higher than a reflection factor of 20% are perceptible. From Figure 2, we learn that the Revealing Power of the lighting is then only about 10% (very low indeed).

To provide a Revealing Power of 80%, for example, for such a lighting system in the Reversed Silhouette Vision, the critical object should have a reflection factor of about only 2% (dark black) and it must be perceived as being brighter than the road surface ahead.

3. 3 Visibility level and the Revealing Power

Recently, the so called Visibility Level of a critical object has been proposed as a quality criterion of the road lighting installation [3] [14].

The Visibility Level (VL) is defined as the ratio between the physical luminance difference (ΔL) of the object in question against its background and the psychological luminance difference thereshold ($\Delta L\mathrm{min}$) of the observer's eyes:

$$VL = (\Delta L) / (\Delta L\mathrm{min})$$

It was shown in the above discussion that the Revealing Power of different lighting installations under which a critical object with an identical reflection factor of 20%, for example, is just perceptible is quite different, depends on the way the object is viewed, namely, in the Silhouette Vision or the Reversed Silhouette Vision.

This means that, even if an object which reflection factor is arbitrarily chosen is perceptible with a high Visibility Level under certain lighting conditions, this by no means automatically implies that all other objects are perceptible with a high Revealing Power as well, unless a reflection factor is chosen to represent a high Revealing Power either for the Silhouette Vision or the Reversed Silhouette Vision, respectively.

It must be emphasized here that the perception of an object under a road lighting installation should not be confused with the perceptibility of the road lighting installation.

4. Expectation and detection

4.1 Spatial distribution of visual acuity

As is well known, the neural structure of the retina is not uniform but has a concentric construction. As shown in Figure 3, the part of the field of vision of human eyes where fine details of the object are perceptible, i. e. , where the visual acuity is high is only the central part (of fovea) around the line of sight with an angular radius of only one or two degrees [15].

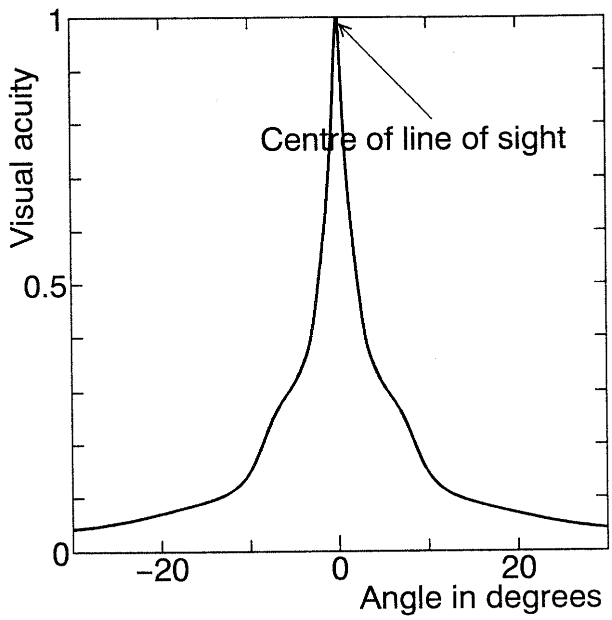

Fig.3 Visual acuity as a function of the angle from the line of sight

This means that the central part of the filed of view takes an aerial extent of only less than 0. 04% of the whole field of view with an angular radius of about 100 degrees.

On the basis of the angular distribution of visual acuity shown in Figure 3, a driver's field of view is imitated and shown in Figure 4. The figure illustrates how the central field where high visual acuity is small, in comparison with the highly blurred peripheral parts of the field of view.

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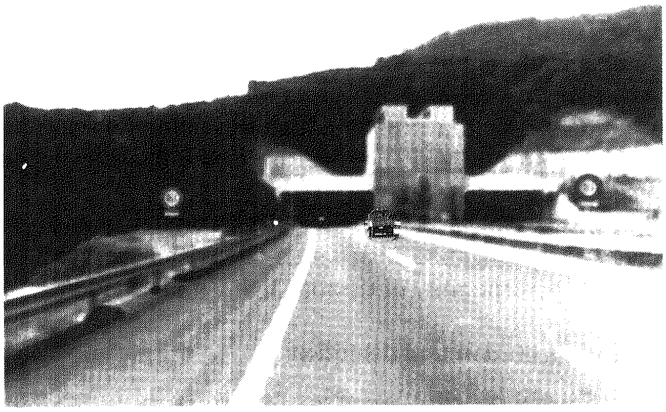

Fig. 4 Imitated driver's field of view

4.2 Eye movements and detection

To make the critical object perceptible,

1) The line of sight of the driver must be directed around the object,
2) The luminance difference (ΔL) between the critical object and the direct background must be higher than the luminance difference threshold ($\Delta L min$) of the driver's eyes.

For this reason, even if the perceptual conditions are fulfilled (the luminance difference between the object and its background is larger than the luminance difference threshold of the observer's eyes), objects in the field of view are not always detected.

Object which luminance difference against its background is equal or larger than the luminance threshold is detectable only when the observer's line of sight is directed around the objects.

Detection of an object in the field of view, therefore, is strongly influenced by unconscious or conscious movements of the observer's eyes. The eyes movements change the direction of the line of sight concerning the object according to psychological situations of the observer, such as, the will to or the necessity to find the object, etc. The eye movements are sometimes activated by the information detected in the peripheral field of view, if it has a sufficient luminance difference for the peripheral background against which the information is seen.

The central field of the eyes which aerial extent is only about 0. 04% of the whole field of view needs at least 0.1 seconds to perceive details of a point to which the line of sight is fixed [16].

Furusho et al., have conducted experimental investigations concerning eye movements of the lookout on board various vessels cruising at normal speeds (between 22 and 28 km/h) and a very high speed (about 83 km/h) [17] [18]. The eye movements have been recorded with the so called eye-pointer fixed on the lookouts' head which orientation was fixed to the vessels.

They compared the speed of eye movements and the duration during which the lookouts fix their visual attention at a point in their field of view between daytime and nighttime, and between little traffic and heavy traffic.

For the very high speed vessel (Jet-foil) cruising at a speed of about 83km/h on a wide sea with little water traffic, for example, the speed of eye movements in daytime was high (about 50 degrees per second) whereas in nighttime it was slow (about 15 degrees per second), and the duration at nighttime increased from about 0.07 seconds in daytime to about 0.11 seconds [17].

For this reason, if one want to perceive all the details in a part of the field of view which spatial extent covers roughly the whole field of view at night, he needs much longer time than that in daytime.

Even with rapid eye movements, therefore, drivers cannot perceive all the details of the rapidly changing field of view while driving.

Consequently,

a) When the driver knew in advance the location where the object to be perceived existed, then the object is detected most easily, since the driver's line of sight is directed quite near to the object,
b) When the driver is expecting that an object will be somewhere in a part of the field of view, then the detection is fairly easy. Since the driver, by scanning rapidly and consciously his line of sight over the part of the field of view where the object is expected to exist, will easily find the object,
c) When the driver does not expect any object to be present, then detection is most difficult or takes a long time. Since the driver's line of sight is directed randomly in the field of view and no conscious efforts to find an object will be made unless the driver feels danger or object seen in the peripheral pert of the field of view attracts the driver's visual attention.

4.3 Field Factor for headlighting

Roper and Howard[19] have carried out an experimental investigation concerning the effects of expectation on detection distance under head lighting conditions. They employed 46 observers driving cars and compared the distance at which the object was detected against the dark background when the observers expected the object and when they did not expect it.

As a result, as shown in the Figure 5, they have found that the detection distance when the observers did not expect the object was considerably shorter than that when expected. In other words, about 50% of the observers could not detect the object until they came to a point at a distance to the object of about 50% of that when they expected.

Such a difference in the detection distance (if the influence of the variations in the apparent size of the object due to changes in the detection distance can be ignored) corresponds to the difference in the illuminance or the luminance of the object detected.

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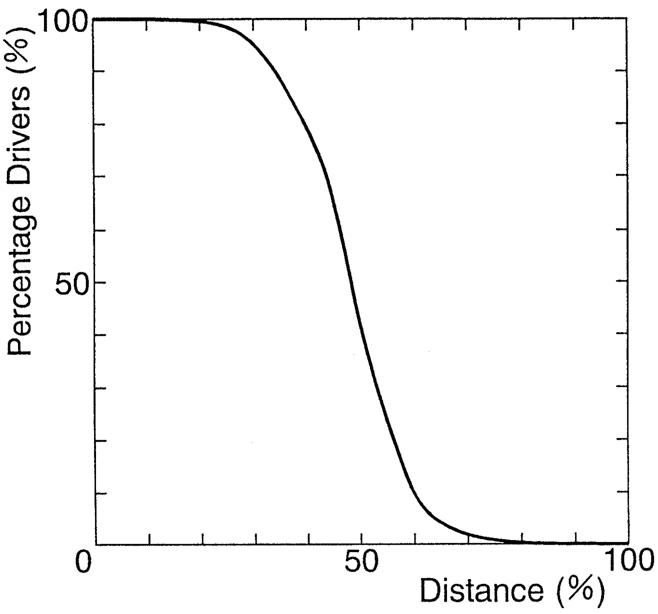

Fig.5 Relationship between the detection distance and the percentages of the observers (Roper and Howard)

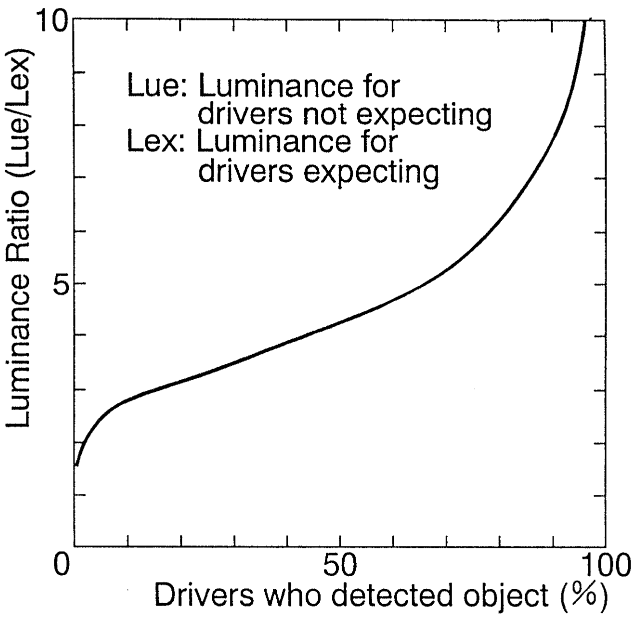

Fig.6 Relationship between the illuminance or the luminance of the object perceived, and the percentages of the observers (Roper and Howard-Narisada)

Since the object was detected against a dark background, the luminance also corresponded to the luminance difference threshold ($\Delta Lmin$).

The result of Roper and Howard shown in Figure 5 have been re-drawn as shown in Figure 6. It shows the cumulative percentage of drivers who detected the object against the dark background and the ratio of the luminance of the object (Lue/Lex) just detected when the observers were not expecting (Lue) and the luminance when they are expecting it (Lex). The luminance ratio is called here the Field Factor [20].

As in Figure 6, to enable 50% of the drivers able to detect the unexpected critical object, its luminance had to be increased to about 4 times that of the expected objects. Similarly, to enable 80% of the observers to make a detection, a luminance of about 6 times of the luminance of the expected object is necessary.

4.4 Field Factor in Road and Tunnel lighting

The results obtained by Roper and Howard have also been used for road lighting [21] and tunnel lighting [20] by a number of investigators. The perceptual condition in these types of lighting, however, is not the same as for headlighting.

Under headlighting conditions, the driver's field of view is dark and he may detect some objects if they are illuminated sufficiently. When nothing is visible to them in dark areas, however, they cannot judge with confidence whether objects existing are difficult to perceive or no object is there.

For this reason, the driver's visual attention scatters randomly over a wide range of dark areas in his field of view. This makes it difficult to detect any objects existing in the dark areas unless the driver's line of sight is directed incidentally to the objects.

On the other hand, when road lighting is installed and the road surface in the driver's field of view where important objects may appear is lit fairly uniformly, observers can judge rather easily where there are no objects or no danger.

Consequently, the driver can concentrate his visual attention to the places where some danger may be or places where perception is felt to be difficult. Such eye movements will make the Field Factor smaller than that in the headlighting system.

Also, when a driver is approaching the entrance of a tunnel in daytime, the driver can judge that there is no danger on or around the access road brightly lit by daylight. Then, the driver can concentrate his visual attention into the dark tunnel [16] which spatial extent in the field of view is small, just a few degrees in angle. This will make the Field Factor smaller than that in the road lighting.

On the basis of the discussion above, it may be expected that the Field Factor is different depending on the luminance composition in the field of view that require different eye movements for the drivers.

For this reason, if one intends to use the results obtained by Roper and Howard for other fields of lighting, careful consideration is always necessary. At this moment, unfortunately, there is no widely known and published investigation concerning the Field Factor for these fields of lighting.

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Fig. 7 Driver's field of view under road lighting conditions

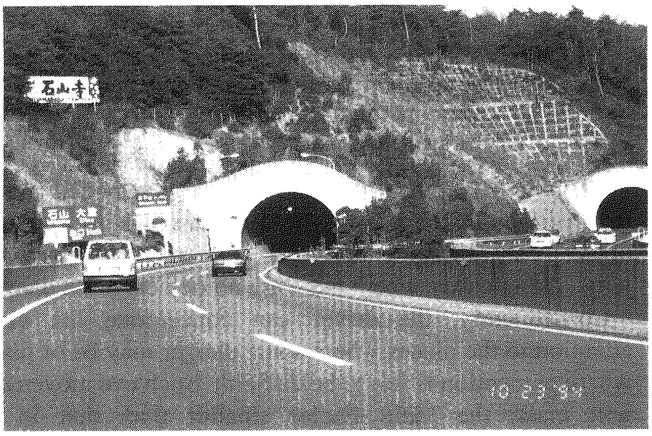

Fig. 8 Driver's field of view approaching the entrance of a tunnel in daytime

5. Road lighting and luminance difference threshold

5. 1 Equivalent Veiling Luminance (Leq)

Incident lights from glare sources scatter in the ocular media in the observer's eyes and cause a veiling. The veiling superimposes over the field of view and consequently, according to its luminance, increases the luminance difference threshold (ΔLmin).

The luminance of a physical veiling between the object to be perceived and the observer's eyes which produces just the same increase in the luminance difference threshold (ΔLmin) as caused by the glade source is called as the Equivalent Veiling Luminance (Leq) for the glare source [22] [23] [24].

Holladay [22] derived, the following formula to calculate the Equivalent Veiling Luminance (Leq) in relation to the vertical illuminance (Ev) on the cornea of the observer's eyes in lx and the angular displacement (θ)of the point glare source as to his or her line of sight in degrees. The value 9.2 is a constant.

$$Leq\ (cd/m^2) = 9.2\,Ev/\theta^2$$

Crawford [23] has found that the Equivalent Veiling Luminance (Leq) caused by a number of glare sources is equal to the sum of the individual Equivalent Veiling Luminance (Leq) caused by each glare source.

Moon and Spencer [25] extended the formula derived by Crawford into an integral form applicable to the large sized sources. Applying the integral formula, they have found that the amount of the Equivalent Veiling Luminance (Leq) caused by a large uniform field whose spatial extant occupies all the field of view is about 7% of the luminance of the uniform field [25]. This is important to know for tunnel lighting.

Fry and others [26] have developed an optical lens that integrates all the Equivalent Veiling Luminance (Leq) caused by all componential bright areas and glare sources in the measuring field. The lens, applied on a normal luminance meter, enables one to measure the Equivalent Veiling Luminance (Leq) at any non-uniform field.

The same can now be done with CCD cameras well [27].

5.2 Equivalent Veiling Luminance and perception

As previously stated, the Equivalent Veiling Luminance (Leq) superimposes over the field of view uniformly and increases the Luminances in the field of view. Consequently, the adaptation luminance of the retina, including fovea, increases.

Accordingly, the sensitivity of fovea decreases and the luminance difference threshold (ΔLmin) increases. This is the physiological effect of the Equivalent Veiling Luminance (Leq) on perception [28].

On the other hand, the Equivalent Veiling Luminance (Leq) superimposed increases the luminances in all parts in the field of view, while keeping all the luminance differences (ΔL) among every part in the field of view unchanged. As a result, the luminance contrast of the object to be perceived against the background decreases and perception deteriorates. This is the physical effect of the Equivalent Veiling Luminance (Leq) on perception [28].

The Equivalent Veiling Luminance (Leq) is caused not only by the glare sources but also by the bright surfaces around the object [25]. This is the cause of the deterioration in perception of small objects against darker parts of the road surface when the overall uniformity (Uo) is low: (the brighter areas act as glare sources).

This means that the deterioration in perception due to the overall uniformity (Uo) as well as the glare on perception is caused by the Equivalent Veiling Luminance as well.

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5.3 Luminance difference threshold and Luminances

To perceive an object, the difference in the luminance (ΔL) between the object and the direct background must be larger than the luminance difference threshold (ΔLmin) of the observer's eyes.

The luminance difference threshold (ΔLmin) of the observer's eyes looking at the critical object whose size is 20cm is determined by:

a) Duration of object presentation (t)
b) Distance to the critical object (d)
c) Luminance of the background (Lb)
d) Equivalent Veiling Luminance caused by the whole field of view (Leq)
e) Foveal adaptation luminance (Lf)
f) Field Factor (FF).

The luminances Lb and Leq are physical stimuli at the moment when the observer is looking at the critical object. The foveal adaptation is a physiochemical process in the retinal elements and requires some time make changes[(29) (30)]. For this reason, the foveal adaptation cannot follow the rapid changes of the luminance projected onto the fovea. The luminance to which the sensitivity of the foveal is adapted is a kind of time average of changing luminances projected onto the fovea during the past minutes. This luminance is called the foveal adaptation luminance (Lf).

6. Experiments on the luminance difference threshold

Narisada and Yoshimura[(28) (31)] have carried out experiments concerning the relationships between the luminance difference threshold (ΔLmin), and the Equivalent Veiling Luminace (Leq) and the foveal adaptation luminance (Lf), respectively.

6.1 Experimental set up

Figure 9 shows a schematic construction of the experimental set up used.

A square object (Oj) with an angular size of 10 minutes was observed against a circular background (B) with an angular size of 1.3 degrees.

Between the observer (Ob) and the object (Oj) presented against the background (B), a half mirror (HM) was placed. Thye object (Oj) was presented for 1/8 seconds. The half mirror (HM) reflected the image of a bright luminous panel (P) in a circular shape with an angular diameter of 3 degrees to the observer (Ob) and produced a veiling luminance between the observer (Ob) and the object (Oj). The luminous panel provided in the light box (LB1) was illuminated from behind by means of tubular fluorescent lamps fed through dimmers.

The reason the angular size for the background (B) and the veiling chosen was small was to eliminate possible influence of the Equivalent Veiling Luminance (Leq) caused by the surrounding parts of these bright surfaces.

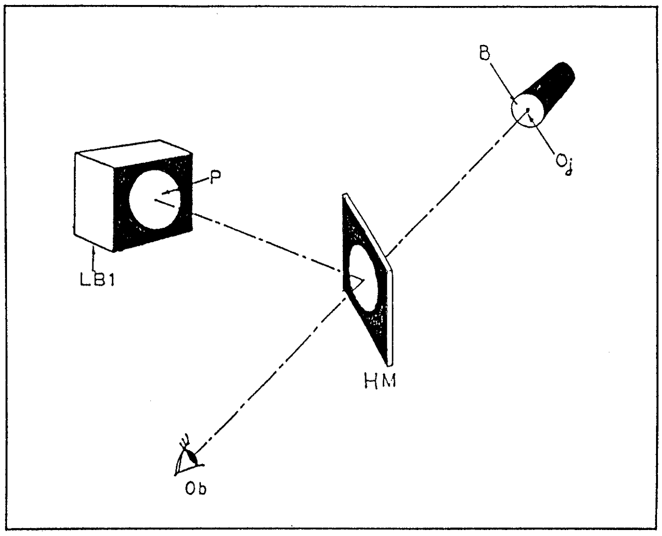

Fig.9 Schematic construction of the experimental set up

The observer viewed the object (Oj) against the background (B) (Luminance:Lb) through the veiling (Luminance:Lv) or without the veiling, according to the experimental procedures. To avoid possible influences of the background luminance (Lb) on the luminance difference threshold (ΔLmin), a much lower luminance than the luminance of the veiling (Lv) was provided on the background (B).

6.2 Observation procedures

Applying the experimental set up, as mentioned already and shown in Figure 9, two series of observations were carried out.

One male observer aged 28 participated in the observations. He repeated the observations 10 times for one given experimental condition at 10 second intervals. In Figure 10, difference in the field of view in the two series of observations are shown.

Before the observations, after complete dark adaptation, the observer's eyes were pre-adapted to the luminance of the veiling (Lv) (the right side of the figure9.

In the first series, the object was observed through the veiling (Lv) to the luminance of which the observer's eyes ware pre-adapted. In the second series, just before the moment when the object was presented, the veiling disappeared and just after the disappearance of the object the veiling appeared again. The object, therefore, was viewed without veiling.

The time during which the veiling disappeared was determined to eliminate possible masking effects[(28) (31)] due to disappearance and reappearance of the veiling superimposed.

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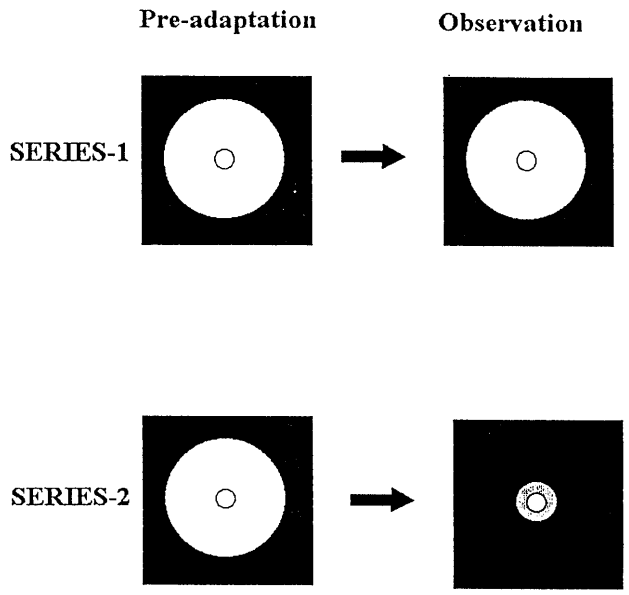

Fig. 10 Difference in the field of view of the observer during pre-adaptation and during observations in the two experimental series.

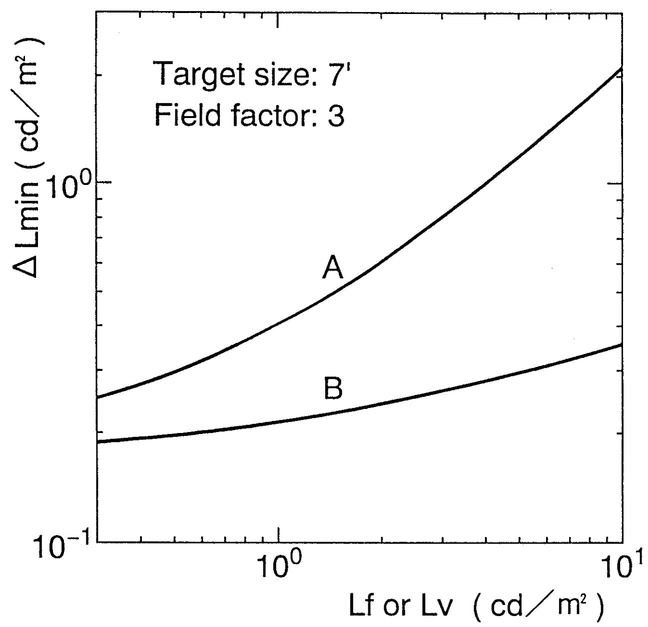

Fig. 11 The luminance difference thresholds observed with the veiling and without the veiling

6.3 Experimental results

As stated earlier, the foveal adaptation cannot follow rapid changes of the luminance during the object presentation of 1/8 seconds. This means that the foveal adaptation luminance (Lf) in the two series of observations was kept the same. The luminance difference thresholds (ΔLmin) as obtained by the observer, however, were not the same.

Following Blackwell [34] and Adrian [9] [35], the original values of the luminance difference threshold (ΔLmin) were multiplied by a factor of 2.5 to correct for the influence of the size of the object from 10 minutes to 7 minutes. The size of 7 minutes corresponds to the angular size of the critical object with a height of 20cm seen about 100m ahead. This is one of widely used criterion for traffic safety [9]. The values were again multiplied by a factor of 3. This was an assumed Field Factor based on the discussions in 4.3.

The results are shown in Figure 11 as two curves A and B.

Curve A in Figure 11 was obtained with the first series under which the object was observed through the veiling. Curve B was obtained with the second series when the object was observed without veiling. (The curves in Figure 11 are a replotting of the experimental data and slightly different from those formerly published [28] [31]).

The horizontal axis shows the luminance of the veiling (Lv) to which the observer's fovea was pre-adapted. The vertical axis gives the corresponding luminance difference thresholds (ΔLmin).

6.4 Survey of the results

As explained above, Curve A in Figure 11 corresponds to the luminance difference thresholds (ΔLmin) observed through the veiling. This implies that the luminance difference threshold (ΔLmin) given by Curve A consists of two componential luminance difference thresholds. These were the componential luminance difference threshold (ΔLmin) for foveal adaptation luminance (Lf) and that for the veiling luminance (Lv) through which the object was observed.

Curve B in Figure 11, on the other hand, shows the luminance difference threshold (ΔLmin) determined solely by the foveal adaptation luminance (Lf).

The difference in ΔLmin between Curve A and Curve B for each value of the foveal adaptation luminance (Lf) gives ΔLmin increased by the veiling luminance (Lv) superimposed over the field of view.

Curve C in Figure 12 shows the difference in the luminance difference threshold (ΔLmin) between Curve A and Curve B in Figure 11 and gives the relationship between the veiling luminance (Lv) and the luminance difference threshold (Δlmin), irrespective of the foveal adaptation luminance (Lf).

As seen in the figure, Curve C is almost a straight line with an inclination of 45 degrees. In the figure, Curve B in Figure 11 is shown again.

By using the two curves in Figure 12, the luminance difference threshold (.ΔLmin) can be derived for any complex luminance fields under road lighting conditions.

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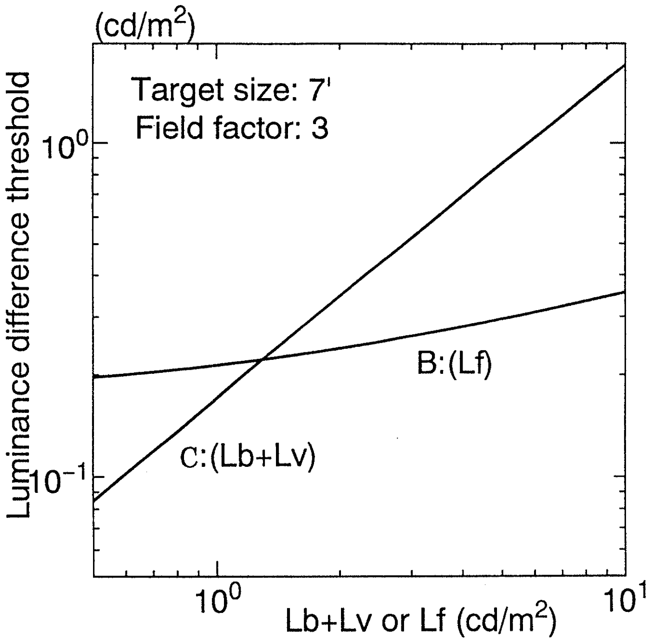

Fig.12 Relationship between the luminance difference threshold and the foveal adaptation luminance (Curve B), and the veiling luminance (Curve C)

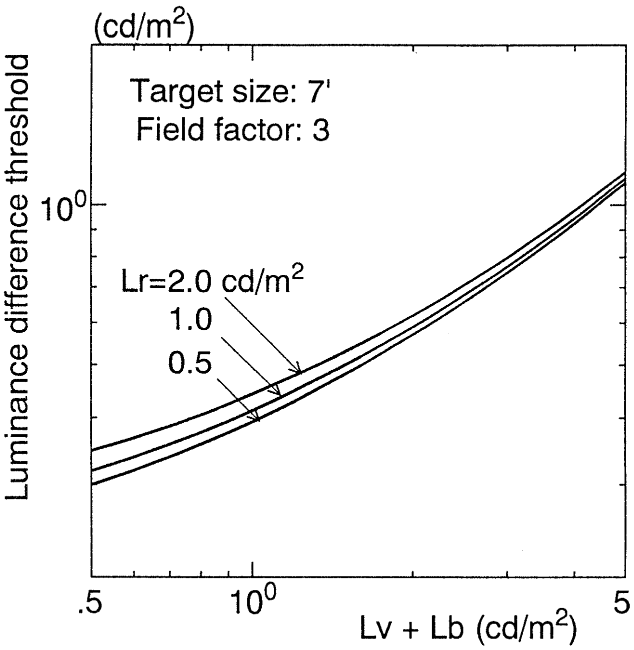

Fig.13 Relationship between the luminance difference threshold and, the sum of the background luminance and Equivalent Veiling Luminance

Curve B, the variation in the corresponding luminance difference threshold (ΔLmin)due to changes in the foveal adaptation luminance (Lf) is relatively small. For this reason, the influence of the accuracy in the assumed value of the foveal adaptation luminance (Lf) upon the luminance difference threshold (ΔLmin) is negligible.

The horizontal axis of Figure 12, corresponding to Curve C (liner line C) in the experiments, is the luminance of the veiling (Lv) through which the object was observed. Under actual lighting conditions, however, the driver's fovea does not distinguish between the stimuli of the luminance of the background (Lb) and that of the veiling (Lv) superimposed over the field of view.

This means that the veiling luminance (Lv) in the experiments corresponds to two luminances in practice. One is the background luminance (Lb) and the other is the Equivalent Veiling Luminance (Leq) caused by the luminances in the peripheral parts of visual field, including glare sources.

For this reason, the horizontal axis of Figure 12, for practical applications, is taken to be the sum of the background luminance (Lb) and then Equivalent Veiling Luminance (Leq).

The luminance difference threshold (ΔLmin) for any complex field under road lighting can be derived by adding up the luminance difference thresholds (ΔLmin), one corresponding to the foveal adaptation luminance, (Lf) and another the sum of the Equivalent Veiling Luminance (Leq) and the background luminance (Lb) against which the critical object is seen.

To simplify the matter, on the basis of Figure 12, the curves in Figure 13 were drawn.

The curves in the figure give the luminance difference threshold (ΔLmin) for the sum (=Lb+Leq) of the background luminance (Lb) and the Equivalent Veiling Luminance (Leq) superimposed. The average road surface luminance (Lr) is taken as a parameter.

By using one of the curves, for its respective foveal adaptation luminance (Lf=Lr), the luminance difference threshold (ΔLimin) can be derived by measuring or calculating the background luminance (Lb) and the Equivalent Veiling Luminance (Leq) for any complex luminance fields.

As the causes of the Equivalent Veiling Luminance (Leq), the road surface around the object brightly lit, the road lighting luminaires, the oncoming headlights, various luminaires inside and outside the adjacent buildings other than road lighting advertizing signs, etc. , can be considered totally or independently.

In this respect, it must be pointed out here that the percentage increment (TI) of the luminance difference threshold (ΔLmin) as specified in the CIE Recommendations (2) (3) is not an appropriate measure to express influences of glare caused by luminaires in the road lighting installations.

First, the Equivalent Veiling Luminance (Leq) caused by the road lighting installation is relatively small portion among whole amount of the Equivalent Veiling Luminance (Leq) caused by many luminous elements mentioned above.

Second, the same amount of percentage increment in the luminance difference threshold (ΔLmin) does not cause the same deteriorarion in the Revealing Power, depends on the actual luminance difference between the critical object and

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the background against which it is seen.

In this way, the influences of the average road surface luminance (Lr), the overall uniformity (Uo) and glare caused by various glare sources on perception can be integrated.

7. Conclusion

Perception in a complex field under road lighting conditions was examined. It was pointed out that the Visibility Level of an object arbitrarily chosen does not necessarily represent perception in road lighting.

Perception in road lighting has to be examined using a critical object whose apparent size and reflection factor are carefully chosen to represent smallest which still is dangerous to traffic and to ensure a high Revealing Power in the Silhouette Vision. On the basis of experimental results, and talking into account a lower Field Factor than that for headlighting, a method to derive the luminance difference threshold (ΔLmin) for any complex field under road lighting was explained.

By applying this method, the influence of the background luminance (Lb), of the Equivalent veiling Luminance (Leq) and of the foveal adaptation luminance (Lf) on the Luminance difference threshold (ΔLmin) can now be dealt with separately.

By means of this method, the quality parameters for road lighting, the average road surface luminance (Lr), the overall uniformity (Uo) and glare from all luminous sources including the luminaires of road lighting, the headlights of oncoming cars, ets. , can be integrated in relation to perception.

To integrate these effects, however, other parameters of the road lighting installations, such as the distribution of the road surface luminance and that of the vertical illuminance, etc. , have to be taken into account. This is out of the scope of this paper and will be discussed in the future.

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